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## LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION AND DRAINAGE.

NOTE.—For those publications to which a price is affixed application should be made to the Superintendent of Documents, Government Printing Office, Washington, D. C., the officer designated by law to sell Government publications. Publications marked with an asterisk (\*) are not available for distribution.

- \*Bul. 36. Notes on Irrigation in Connecticut and New Jersey. By C. S. Phelps and E. B. Voorhees. Pp. 64. Price, 10 cents.
- Bul. 58. Water Rights on the Missouri River and its Tributaries. By Elwood Mead. Pp. 80. Price, 10 cents.
- Bul. 60. Abstract of Laws for Acquiring Titles to Water from the Missouri River and its Tributaries, with the Legal Forms in Use. Compiled by Elwood Mead. Pp. 77. Price, 10 cents.
- Bul. 70. Water-Right Problems of Bear River. By Clarence T. Johnston and Joseph A. Breckons. Pp. 40. Price, 15 cents.
- Bul. 73. Irrigation in the Rocky Mountain States. By J. C. Ulrich. Pp. 64. Price, 10 cents.
- Bul. 81. The Use of Water in Irrigation in Wyoming. By B. C. Buffum. Pp. 56. Price, 10 cents.
- \*Bul. 86. The Use of Water in Irrigation. Report of investigations made in 1899, under the supervision of Elwood Mead, expert in charge, and C. T. Johnston, assistant. Pp. 253. Price, 30 cents.
- Bul. 87. Irrigation in New Jersey. By Edward B. Voorhees. Pp. 40. Price, 5 cents.
- \*Bul. 90. Irrigation in Hawaii. By Walter Maxwell. Pp. 48. Price, 10 cents.
- Bul. 92. The Reservoir System of the Cache la Poudre Valley. By E. S. Nettleton. Pp. 48. Price, 15 cents.
- Bul. 96. Irrigation Laws of the Northwest Territories of Canada and of Wyoming, with Discussions by J. S. Dennis, Fred Bond, and J. M. Wilson. Pp. 90. Price, 10 cents.
- Bul. 100. Report of Irrigation Investigations in California, under the direction of Elwood Mead, assisted by William E. Smythe, Marsden Manson, J. M. Wilson, Charles D. Marx, Frank Soulé, C. E. Grunsky, Edward M. Boggs, and James D. Schuyler. Pp. 411. Price, cloth, \$1.25; paper, 90 cents.
- \*Bul. 104. The Use of Water in Irrigation. Report of investigations made in 1900, under the supervision of Elwood Mead, expert in charge, and C. T. Johnston, assistant. Pp. 334. Price, 50 cents.
- Bul. 105. Irrigation in the United States. Testimony of Elwood Mead, irrigation expert in charge, before the United States Industrial Commission June 11 and 12, 1901. Pp. 47. Price, 15 cents.
- Bul. 108. Irrigation Practice among Fruit Growers on the Pacific Coast. By E. J. Wickson. Pp. 54. Price, 15 cents.
- Bul. 113. Irrigation of Rice in the United States. By Frank Bond and George H. Keeney. Pp. 77. Price, 30 cents.
- Bul. 118. Irrigation from Big Thompson River. By John E. Field. Pp. 75. Price, 10 cents.
- \*Bul. 119. Report of Irrigation Investigations for 1901, under the direction of Elwood Mead, chief. Pp. 401. Price, 50 cents.

[Continued on third page of cover.]

U. S. DEPARTMENT OF AGRICULTURE,  
OFFICE OF EXPERIMENT STATIONS,  
A. C. TRUE, Director.

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# IRRIGATION AND DRAINAGE INVESTIGATIONS

OF THE

OFFICE OF EXPERIMENT STATIONS,  
U. S. DEPARTMENT OF AGRICULTURE.

BY

*Ray Palmer*  
R. P. TEELF,

*Editorial Assistant, Office of Experiment Stations.*



WASHINGTON:  
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June 19-1904  
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## LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,  
OFFICE OF EXPERIMENT STATIONS,  
*Washington, D. C., July 5, 1904.*

SIR: I have the honor to transmit herewith and recommend for publication a brief account of the irrigation and drainage investigations of the Office of Experiment Stations. This account is intended primarily for distribution at the Louisiana Purchase Exposition in connection with the exhibits of this Office in the Government building and of the agricultural colleges and experiment stations in the Palace of Education.

Respectfully,

A. C. TRUE,  
*Director.*

Hon. JAMES WILSON,  
*Secretary of Agriculture.*

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## IRRIGATION AND DRAINAGE INVESTIGATIONS OF THE OFFICE OF EXPERIMENT STATIONS, UNITED STATES DEPARTMENT OF AGRICULTURE.

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By R. P. TEELE, *Editorial Assistant.*

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### HISTORICAL.

The irrigation investigations of the Office of Experiment Stations were first provided for in the agricultural appropriation act of 1898, which contained an item of \$10,000 "for the purpose of collecting from agricultural colleges, agricultural experiment stations, and other sources \* \* \* valuable information and data on the subject of irrigation, and publishing the same in bulletin form." The general supervision of this work was assigned to the Office of Experiment Stations. In order to determine the lines of information most valuable to the regions where irrigation is necessary, a conference of experiment station officers and irrigation engineers who had been prominently connected with western irrigation development was held in Denver, Colo., July 12 and 13, 1897, and was attended by officers of the experiment stations of California, Colorado, Montana, Nebraska, Utah, and Wyoming, and by the State engineers of Colorado, Nebraska, and Wyoming, besides representatives of the United States Department of Agriculture. At this conference it was decided that the best results could be obtained by carrying out this work along two general lines: (1) The collection and publication of information regarding the laws and institutions of the irrigated region in their relation to agriculture, and (2) the publication of available information regarding the use of irrigation waters in agriculture as shown by the actual experience of farmers and by experimental investigations, and the encouragement of further investigations in this line by the experiment stations. The work was organized according to these suggestions, and was, therefore, divided into two classes, the legal and economic, and the cultural. Following the conference, the work was placed under the direct charge of Elwood Mead, at that time State engineer of Wyoming. This action was indorsed by Congress at its next session, when it provided for the investigation of (1) "the laws and institutions relating to irrigation" and (2) "the use of irrigation waters, with especial suggestions



for better methods for the utilization of irrigation waters in agriculture than those in common use." The appropriation for the work was increased to \$35,000.

The original law provided for the collection of information from the agricultural colleges and experiment stations and the law for the succeeding year authorized the stations to cooperate with the Department in the investigation of the subjects specified. In accordance with the law, the work has been very largely done in cooperation, to the great advantage of both the stations and the Department. A small amount of financial assistance from the Department has enabled the stations to extend their experiments in irrigation, while the money thus spent brought to the Department larger returns than could be secured in any other way, since it secured the use of the lands and equipments of the stations free of cost and the services of their investigators by paying only small parts of their salaries. Thus the Department secured for a few hundred dollars the making of experiments which would have cost as many thousands of dollars if carried on independently of the stations.

For the years ending June 30, 1901, and June 30, 1902, the appropriation was increased to \$50,000, but the work authorized was not changed. For the year ending June 30, 1903, the appropriation was increased to \$65,000, and the work was considerably enlarged. The added work provided for included studies of (1) the laws affecting the rights of riparian proprietors; (2) the use of irrigation waters abroad as well as at home; (3) plans for the removal of seepage and surplus waters by drainage; and (4) the use of different kinds of power for irrigation and other agricultural purposes. In the act making appropriations for the Department of Agriculture for 1905 the growing importance of drainage studies was recognized by a change of the title of the investigations to "Irrigation and drainage investigations," and an increase in the appropriation, the section providing for this reading as follows:

**IRRIGATION AND DRAINAGE INVESTIGATIONS:** To enable the Secretary of Agriculture to investigate and report upon the laws of the States and Territories as affecting irrigation and the rights of appropriators and of riparian proprietors and institutions relating to irrigation and upon the use of irrigation waters, at home and abroad; with especial suggestions of the best methods for the utilization of irrigation waters in agriculture, and upon plans for the removal of seepage and surplus waters by drainage, and upon the use of different kinds of power and appliances for irrigation and drainage, and for the preparation, printing, and illustration of reports and bulletins on irrigation and drainage, including employment of labor in the city of Washington or elsewhere; and the agricultural experiment stations are hereby authorized and directed to cooperate with the Secretary of Agriculture in carrying out said investigations in such manner and to such extent as may be warranted by a due regard to the varying conditions and needs and laws of the respective States and Territories as may be mutually agreed upon, and all necessary expenses, sixty-seven thousand five hundred dollars.

## NEED OF IRRIGATION AND DRAINAGE IN THE UNITED STATES.

The rainfall over one-third of the United States is so scanty that irrigation is a necessity to the profitable growth of agricultural crops. In other sections of the country there is an area equal in size to all New England, with Indiana added, which is so wet that crops can not be grown at all, and where settlement and cultivation must be postponed until the land has been diked and drained.

In the fifteen States and Territories of the arid region irrigation is the fundamental agricultural problem, because the very existence of civilized life depends in large measure on the ability to use rivers for this purpose. In these States the production of a cheap and abundant home food supply, made possible by irrigation, has increased the comfort and lessened the cost of living, and contributed in a greater degree than any other single cause to their continued growth and prosperity. By it desert wastes have been transformed into the most productive, healthful, and beautiful habitations of man to be found on this continent. The cities of Denver, Salt Lake, Los Angeles, and many others of lesser note are as much the creation of irrigation as the orchards and farms which surround them, and all depend for existence upon water and the institutions which govern its ownership and use.

In many humid sections of the country high-priced land and intensive methods of cultivation are making of irrigation a factor of continually increasing value and importance, and it would seem that the experience of the United States, like that of Europe, will prove that no agent of agriculture or horticulture is so effective in increasing and insuring large yields as the ability to apply water in the right amount and at the right time.

There are large areas of land which always receive too much water, large areas which never receive enough, and yet larger areas which have sometimes too much and sometimes too little water. Only by proper control of the water supply can these lands be made to produce the best crops, and such a control includes both irrigation and drainage, some lands needing one, some the other, and some needing both. The greater part of the land now farmed in the United States belongs to the last class. The experiments made by this Office and the experience of farmers and gardeners show that irrigation in dry years, even in the regions of heaviest average rainfall, much more than repays the cost of supplying the water. In these regions crops are as often drowned out as burned out, and it is probable that drainage to remove water in wet years will prove as profitable as irrigation in dry years.

The area of land in the United States east of the one hundredth meridian which is too wet for agricultural use but which can be reclaimed

by drainage has been estimated by Prof. N. S. Shaler at from 105,000 to 131,000 square miles,<sup>a</sup> or from 67,200,000 to 83,840,000 acres. It is a notable fact that this is practically the same as the estimates of the area which can be reclaimed by irrigation; that is, the area east of the one hundredth meridian which can be reclaimed by drainage equals that west of that line which can be reclaimed by irrigation. These wet lands have received for centuries the alluvial deposits from the streams which overflow them and the vegetable mold from the rank growth which covers them, so that when relieved of their surplus water they are among our most productive lands, competent authority estimating their productive capacity as being four times that of the State of Illinois.

The irrigation and drainage investigations of the Office of Experiment Stations were established by Congress to study the best methods of utilizing these two aids to agriculture, to determine the best methods of securing, distributing, and applying water to land when it is too dry, and of removing water from land when it is too wet. The following pages will give a brief outline of the work which is being carried on, and of some of the results which have been secured.

### **THE IRRIGATION INVESTIGATIONS.**

While accurate statistics are lacking, it is certain that more than \$200,000,000 has been expended in the United States in the construction of canals and reservoirs for distributing water in irrigation and in preparing land for its application. More than 10,000,000 acres of land are being watered each year and more than 15,000,000 acres are capable of being watered from the canals and ditches already built. The greater part of this water comes from creeks and rivers, hundreds of these being completely emptied at some season each year in order to meet the needs of the fields along their banks. Other ditches are supplied from reservoirs, of which thousands have already been built. Still other ditches are filled from water lifted from wells. In all, the welfare and prosperity of several million homes and the future industrial importance of more than one-third of this country is dependent upon the successful working of the laws and practices for the control and utilization of water which have grown up in the western part of the United States within the past fifty years. The rapidity and extent of this irrigation development has had no counterpart in any other country. It has been carried out by men to whom all its problems were strange and new, and, in many cases, where scanty population, lack of transportation facilities, and limited means on the part of settlers have added to both the difficulty and the cost of the work. The results already secured furnish a remarkable illustration of the

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<sup>a</sup> Fresh Water Morasses of the United States.

energy and capacity of the American farmer, but the time has come when this kind of development should be replaced by one less wasteful and more orderly. Of necessity much of the early work was done in an unsatisfactory fashion, many of the methods of using water are crude and imperfect, and the social and legal organizations under which rivers are now being fought over are not adapted to securing the largest and best results or to meeting the requirements of the time when increasing value of water and greater demand for its use by an increased population will intensify the struggle over its possession. Many of the problems created by this development have already assumed a complexity and importance which makes it plain that their solution can only be effected through painstaking investigation, which will embrace widely scattered areas and be directed and interpreted by men of experience and ability in irrigation engineering and irrigation practice. The investigations during the past five years have been directed toward building up an organization of experts, who shall be investigators rather than construction engineers and who shall study all problems from the standpoint of the farmer.

#### **DUTY OF WATER.**

The first question which confronts the farmer in the arid region is the amount of water required to insure crops on the land he is to cultivate. He needs this information in order to make an intelligent bargain for water where he rents it from a canal company, or to fix the size of the canal he builds himself. He needs to know when this water will be required—how much in May, how much in August—in order to determine whether the stream, reservoir, or well he depends on can supply it. The amount he must have varies widely in different localities and with different products. The irrigation of small grains, as a rule, ends with July; the irrigation of many root crops does not begin before this month, while the irrigation of alfalfa continues throughout the growing season.

He should also be able to estimate how much of the water taken in at the head gate will be lost by seepage in transit, because losses in transit in some instances amount to more than one-half of the total supply. For the past five years the Office of Experiment Stations, through its irrigation investigations, has been gathering and publishing this information for the benefit of farmers and ditch owners. Systematic measurements have been made in all parts of the arid region to determine the amount of water lost in transit in canals, the amount required by different crops, and the manner in which the quantity of water used can be influenced by greater care in the preparation of land, greater skill in the distribution of water, and by improvements to lessen seepage losses in diversion and carriage. Some of the results of these studies are given in charts exhibited at the

Louisiana Purchase Exposition, which show the average quantity of water required to irrigate an acre of land when measured at the head gate, the average when measured at the margin of fields, and the average requirements of different crops.

One of the results of these investigations has been to show that the loss of water from seepage is far more serious than had been generally supposed, even by canal owners and irrigation engineers, and that one of the most promising means of increasing the duty of water is to build better canals and devote more care to keeping them in first-class condition. It has already proven profitable in a few localities to line canals with some impervious coating in order to reduce or prevent seepage losses. Many miles of canals and ditches in southern California have been cemented at a profit (Pl. I), and the extension of this sort of work is only delayed because of uncertainty as to whether or not cementing is the cheapest and best means of securing a water-tight conduit.

One of the first difficulties encountered in the beginning of this work was the lack of an accurate, simple register to keep a continuous record of the water used. All those which were satisfactory were at that time imported from France. To-day they are practically all made in this country, a result which is chiefly due to the irrigation investigations of this Office. Designs of instruments were made by the experts, as experience showed what changes could be made to advantage. The drawings were given to the makers of such instruments. Some of the instruments which had their origin in the designs prepared by this Office, and which have been perfected in details by the various makers are shown in figures 1, 2, and 3.<sup>a</sup> They are now superior to anything used in the irrigated districts of Europe.

The accurate measurement of water is the first requisite in the efficient division of a river among those entitled to its water supply. In the preparation of weir tables, directions for placing weirs, and in discussion of the factors which influence water measurement, this Office has done much to direct and aid improvement along this line in every arid State.

Actual measurements of the quantity of water used in irrigation, and of the volume lost by seepage and evaporation in ditches, should have been made at the very outset in irrigation development in every important valley of the West. It is the only way in which a reliable guide can be had for framing water-right contracts between farmers and canal owners, and to enable courts to make a just and intelligent adjudication of rights to a stream. In order that an appropriation of water shall be limited to beneficial use we must first know how much is needed to supply that use.

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<sup>a</sup>These instruments are shown in the exhibit of the Office at the St. Louis Exposition.

CEMENT-LINED CANAL, CALIFORNIA.





To show how little was known in the early settlement of these questions, it may be stated that along a stream 25 miles in length the amount of water bargained to be supplied under the early contracts varied from enough to cover the land to a depth of 1 foot in the season to enough to cover it to a depth of 7 feet during the same time, while the decrees of the court establishing rights to water varied from enough to cover the land to a depth of 1 foot in a season to enough to cover it to a depth of 400 feet in a season. The use made of the measurements carried on by this Office during the past five years by courts, legislators, ditch companies, and farmers has shown the need of these data. The averages obtained show that much more water is used than is needed, and lead to the belief that the water now used on one acre can, by better preparation of land and more skillful application, be made to serve two acres. General rules are not, however, sufficient for the working out of a satisfactory irrigation practice for the whole arid region, because soil, climate, and crop each influence the result and produce widely varying requirements in different sections. More than three times as much water is needed in Arizona as in Montana, because the summers are hotter and the growing seasons longer. What is needed, therefore, is investigations which will be sufficient in number and wide enough in geographical distribution to furnish an approximate guide for the practice of farmers in all sections of the country.

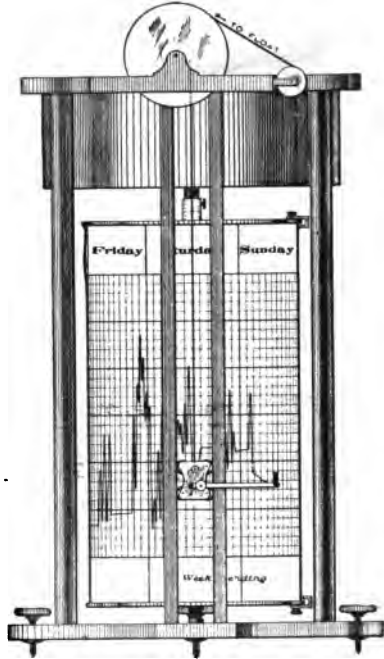


FIG. 1.—The Wyoming nilometer.

The earlier investigations dealt wholly with the quantity of water required under methods in common use. During the past two years a new series of original researches have been inaugurated, to determine what quantity of water will give the best results and what methods of application will secure the greatest economy in its use. A large number of experiments are being made in Utah, California, Oregon, and Montana, in which different quantities of water are being applied to the same crop by the same methods, in order to determine where the increased use of water ceases to be profitable, and also where it ceases to be beneficial. We wish to find out two things: What volume of water will give the largest yield for an acre of land, and what volume will give the largest return for each acre-foot of water used. Experi-



ments are also being made to determine what method of application will give the best results with the least loss of water from seepage and evaporation.<sup>a</sup> While the experiments were only begun last year, the results are most significant—nearly twice as much water being required

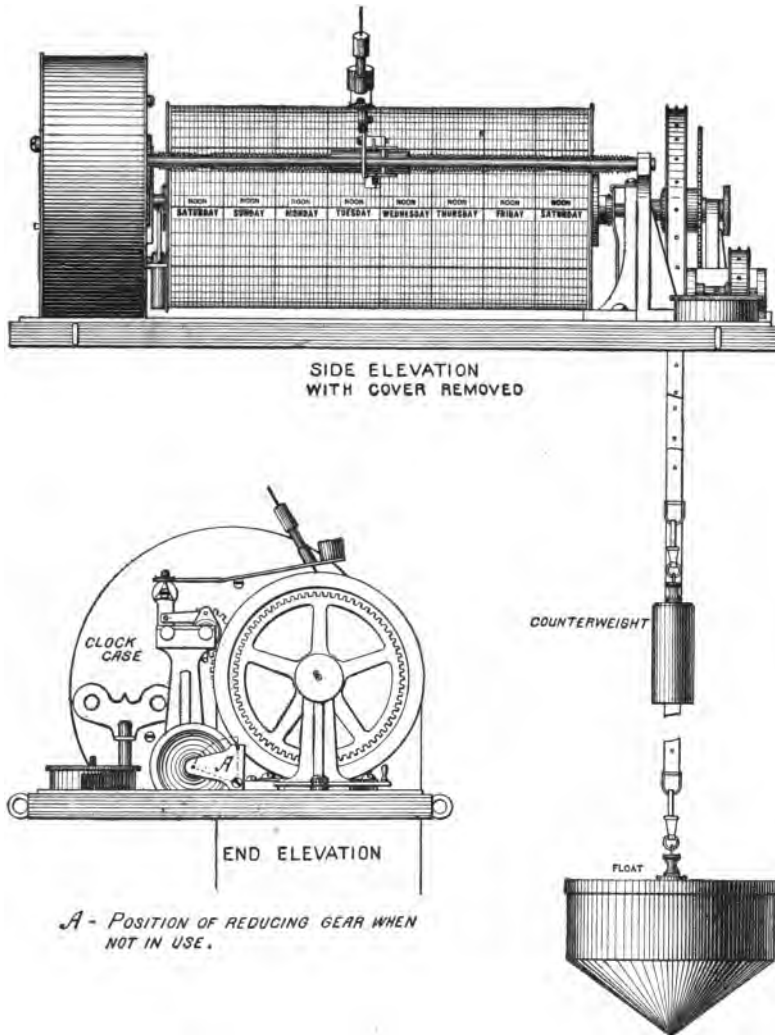


FIG. 2.—Friez water register No. 2.

to irrigate land by flooding as will serve where it is applied in deep furrows.

These investigations have also disclosed the fact that the character of water rights has an important influence on the volume of water

<sup>a</sup> Pictures of the tank experiments at Fresno, Cal., displayed in the exhibit at St. Louis, show how some of these studies are being carried on.

used in irrigation. Contracts which are based on the acres irrigated are a direct incentive to a wasteful use of water, because the farmer feels that the more water he uses on an acre the more he will get for the money paid. On the other hand, contracts which base the rental charge on the volume of water used encourage farmers to exhibit skill and economy in its application, because the less they put on their fields the smaller their water rentals will be. It makes it profitable to expend more money in the preparation of land, to put ditches in better condition, and to supplement irrigation by thorough cultivation.

After the water supply is secured, fields must be prepared for its application. The cost, the labor, and the skill required in putting an uneven surface in condition to have water reach, by gravity, every

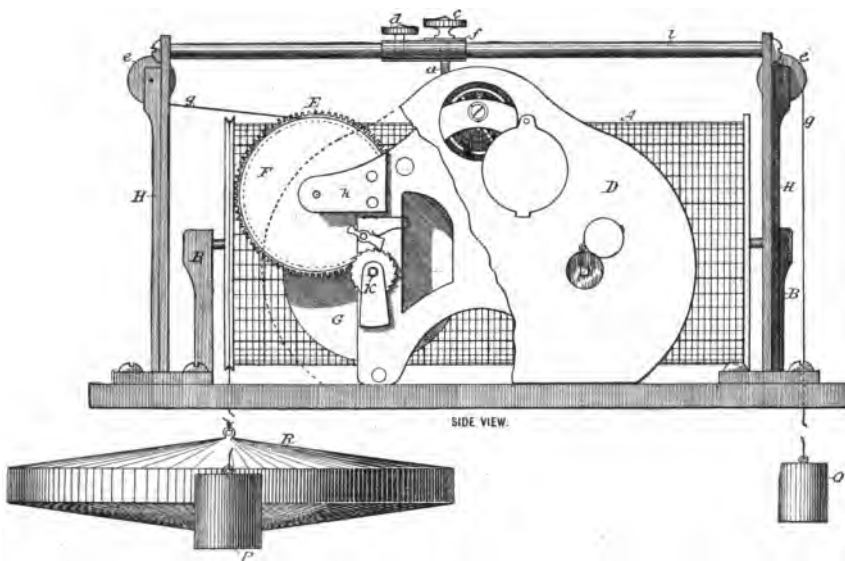


FIG. 3.—Water register manufactured for the Department (side view).

square foot of its surface have never been rightly appreciated. So much attention has been given to problems connected with the building of dams and canals that the work of the farmer, which, after all, determines what value the dams and canals are to have, has been neglected. No one who has made a study of our irrigation practice can fail to reach the conclusion that the outlay expended in preparing fields for the application of water, which includes removing brush, leveling uneven areas, and the building of laterals, is on the average equal to or greater than the cost of the main canals. Not only is this true, but, owing to lack of information regarding the methods of applying water, much of this money and labor has been lost. This waste and loss is going on continually, because each year tens of thousands of beginners in irrigation undertake the reclamation of new lands. If left to themselves they adopt the methods of their neighbors, without regard to

whether they are suited to their conditions. In too many instances they are not. There are in this country about thirty different systems of applying water to crops. To know which one of these is best suited to a particular farm requires a knowledge of the subject not possessed by the average irrigator or the average engineer. Nothing will do more to promote rapid and successful settlement of lands now arid than to show farmers how to save money and time in grading land and building laterals; but in order to advise regarding this, field investigations which will give an accurate idea of conditions are absolutely indispensable, and these are being made and reports prepared.

The results of studies of this kind made in one district show that to prepare the land for irrigation by the plan first adopted would involve an outlay of more than \$3,000,000, or about twice the amount needed to build the canal. It has also been made apparent that fully half of this outlay can be saved by the adoption of a different method of applying water.

#### **LEGAL AND ECONOMIC PROBLEMS.**

When there is more water in the stream than all the irrigators need, farmers pay little attention to the nature of their rights to divert its flow; but as ditches increase in number until the stream does not carry enough water to supply all, the question of which head gate must be closed and which farmer must lose his crop because of this shortage becomes a matter of overshadowing importance. It is then that the irrigator with an imperfect right realizes that a valid title to water is more important than a title to land. The knowledge of his own lost labor, ruined crops, and his fields parched by drought is aggravated by the prosperity of his neighbors whose superior rights in the stream keep their ditches filled and their fields wet. In the absence of laws to govern the division of the water supply, or of agreements to regulate such division by mutual consent, the position of a canal on the stream determines whether it has an abundant or scanty water supply. The irrigator whose ditch is nearest the head of the stream, or whose lateral is nearest the head of the canal, uses or wastes water as he pleases. Those farthest down must take what is left, and when waste or use has exhausted the supply it is always the irrigator at the lower end of the stream or the farther end of the canal who is the first to suffer. To prevent the waste and injustice inevitable on such canals, there has been built up in each Western State a system of legal and social institutions intended to govern the relations of water users to each other and to determine and protect their rights to the water supply. As settlements have multiplied, demands on the streams have increased, and irrigators have come to realize that on the wisdom and justice of these institutions depend in large measure the value of irrigated land and the security, peacefulness, and profit which attend their work.

The Arkansas River in Colorado will serve to illustrate the importance of the social and legal problems of irrigation. One thousand nine hundred ditches divert this river in that State. Their aggregate length, exclusive of laterals, is more than 3,000 miles. About \$9,000,000 has been expended in their construction. Six hundred thousand acres of land can be watered from them, and more than 400,000 is now being irrigated. Between 7,000 and 8,000 people depend on these ditches for their water supply, and they have invested large sums of money in the purchase of stock in the companies, in buying water-right contracts, or in the payment of annual water rentals. The value of the irrigable land thereunder is between \$25,000,000 and \$30,000,000. The cost of operating and maintaining these works is over \$200,000 a year. Each one of these 8,000 irrigators knows that in order to grow a crop he must have his part of the water of the river at the time the crop needs it, and that if some other canal or some other irrigator takes his share his crops will be ruined, no matter how industrious or skillful he may be in their cultivation. With 8,000 irrigators scattered over a territory more than 200 miles in length and in places 50 miles wide, he also knows that he is dependent for his share of the water supply on the nature of the arrangements for preventing waste on the part of others and on the efficiency of the division of the stream between the 1,900 ditches which divert it. Unless the head gates of these ditches or canals are so adjusted that no one can take more than its proper share, and unless those not entitled to water are closed entirely when the protection of superior rights requires it, there must inevitably be injustice, bitterness of feeling, and failure of crops.

The final problem of irrigation becomes one of distribution and, to make this a success, the arrangements for transporting water to the laterals of the different farms should be carried out with the same order and system that marks the management of a railroad or express company. The difficulty of securing a satisfactory division of a river among irrigators is enormously increased by the fact that the volume of water to be divided is never uniform. It varies from day to day and from season to season. The flow of the Arkansas, for example, has been as high as 40,000 cubic feet per second and as low as 100 cubic feet per second. At its highest stage there was more water than all the canals could carry and the integrity of head gates was threatened. At its lowest stage there was not enough to wet the flumes. Irrigation on this stream has already been so extended that without storage of flood waters the crops on many fields must each year be parched by drought, and great storage reservoirs have been built and others are contemplated in order that the 200,000 acres of land under existing ditches, not yet irrigated, may be brought under cultivation. The water of many of these reservoirs has to be turned

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